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Near-Field Impulse Loading Measurement Techniques for Evaluating Explosive Blast

by Thuvan Piehler, Avi Birk, Richard Benjamin, Vincent Boyle, Eugene Summers, and Stephen Aubert

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14. ABSTRACT

Near-field blast loading on a target and the correlation between the charge design and blast impulse were determined and evaluated by using the U.S. Army Research Laboratory (ARL) blast bar gauge and the ARL blast integrator (BI) device. The term near-field refers to a distance less than or equal to ten charge diameters. The pressure-time data used as a measurement of blast loading were obtained using the ARL blast bar gauge mounted in a blast chamber. The ARL blast bar gauge and electrical circuit were tested and calibrated successfully. The total impulse measurements were obtained using the BI device. The blast was generated by a two-inch diameter by four-inch long cylindrical charge simultaneously initiated at both ends. This report describes the experiments and summarizes the results.

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measurement techniques, blast performance, near field blast, impulse loading, explosives

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INTRODUCTION

Near-field distance refers to a standoff distance less than or equal to ten charge diameters. At a near-field distance, the peak pressure behind the blast wave is of the order of 100MPa. The peak reflected values are in excess of 1000 MPa. [1]. The severity of the environment creates extremely difficult demands on the instruments for measuring the near-field blast effects produced by an explosive charge. Instruments to measure these effects have to be robust enough to survive. The main goal of this work is to better understand the blast effects of an explosive charge in a near-field environment and evaluate the performance of explosive formulations. ARL developed two devices: a blast integrator (BI) device and a blast bar gauge. The BI based on momentum transfer was used to reliably measure the total impulse of an explosive charge on a steel column. For time resolved pressure history, a blast bar gauge based on the Hopkinson bar technique was constructed and developed at ARL. By integrating the pressure time signal, the impulse per unit area of an explosive charge on the face of a bar was calculated.

EXPERIMENTAL SETUP AND INSTRUMENTATION

The main experimental arrangement used in this study included the ARL blast bar gauge and the BI in an indoor blast chamber as shown in Figure 1. A cylindrical explosive charge, two inches diameter by four inches long, was placed so that its axis was parallel to the axis of the blast integrator column. The standoff distances were from the center of the charge to the center of the column and to the face of the blast bar gauge. An RP-80 detonator and pentolite booster were used for initiation. The functioning time reproducibility for the initiator was less than 0.5 μs. The charge was simultaneously initiated at each end in order to produce an enhanced blast wave when the detonation waves met at the center. Time of arrival of the blast wave front was recorded using five piezoelectric pins at equal distances from the axis of the charge.
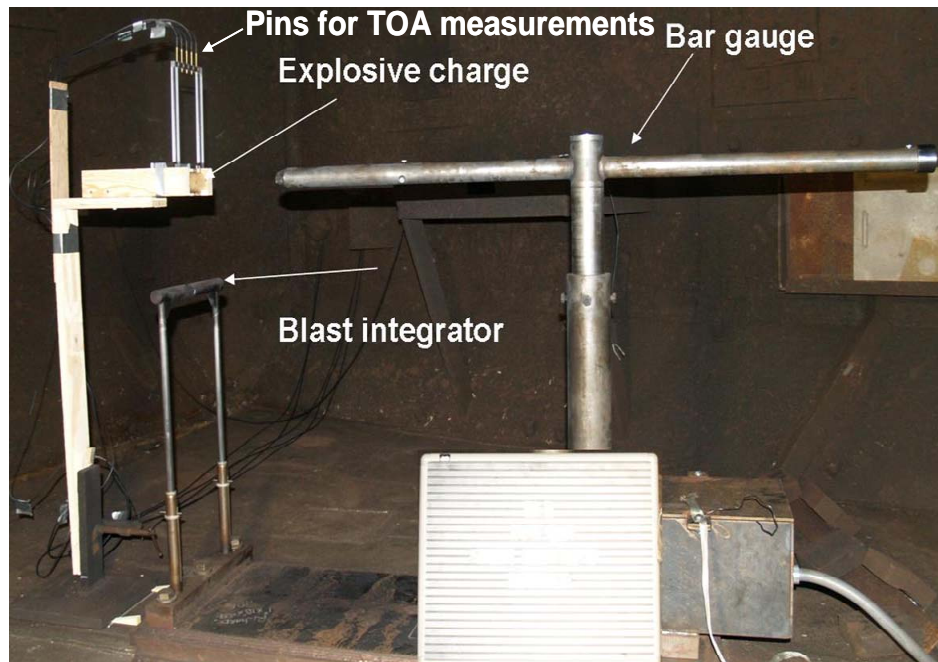
Figure 1: The main experimental arrangement

ARL Blast Bar Gauge

The time-resolved pressure history and the impulse per unit area on the face of the bar gauge were obtained by using a blast bar gauge based on the Hopkinson technique as shown in Figure 2. The device consisted of a 0.5" diameter x 59" long Vascomax 350 steel bar enclosed within a 1.75" outer diameter x 1" inner diameter steel pipe. The far end of the bar was supported by a brass sleeve and the near end (impact end) was supported by a Vascomax 350 steel nose plug, which helped to protect the bar. There was 0.002" of clearance between the bar and the nose plug, which was filled with grease. A 0.010" thick steel shim covered the nose plug and rod faces. The far end of the steel pipe was closed by a threaded steel end cap. Two foil strain gages (Vishay Micro-measurements 2-element, 90^0 tee rosette, 350 ohms) were attached to the bar at the mid-point as shown in Figure 3. A Wheatstone bridge is used to determine the change in resistance that occurs when the gauges are subjected to strain. The gauges were connected electrically using a four-arm Wheatstone bridge arrangement shown in Figure 4. Each arm can be either a gauge or a dummy resistor depending on the desired configuration. A steel box containing the Wheatstone bridge circuit, called the housing unit, was welded to the base plate. The housing unit is shown in Figure 5 and consists of a metallic electronics enclosure contained inside a steel box. Two RG-58 output signal lines were run from the steel box to a digital oscilloscope located outside the blast chamber.
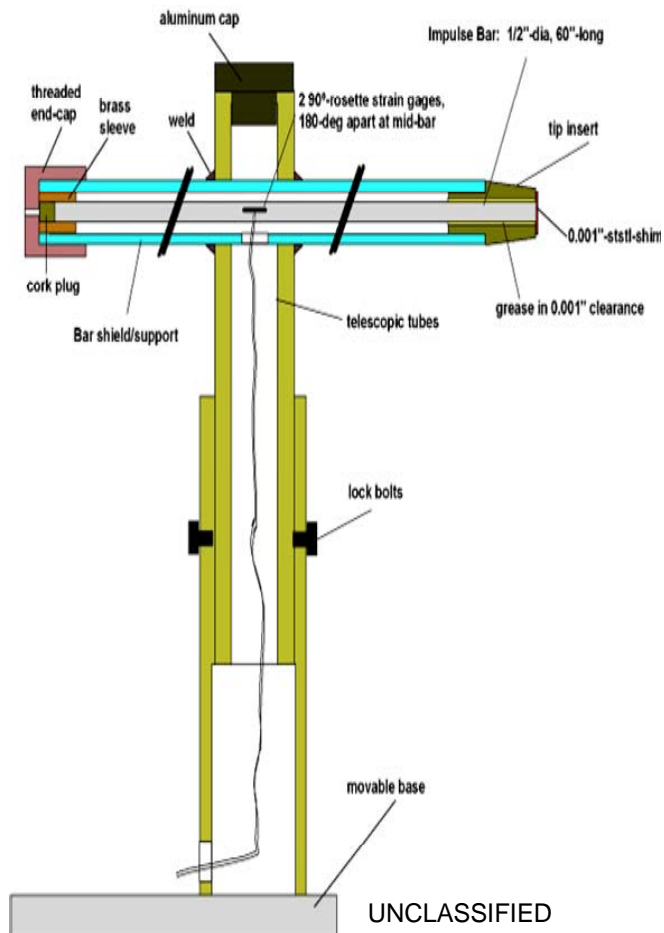
Figure 2: ARL Blast Bar Gauge Setup
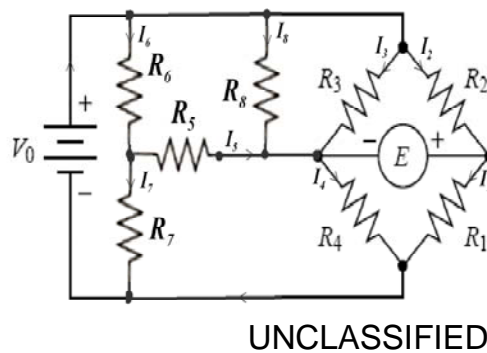

Figure 3: Strain Gauges Attached on a Steel Bar

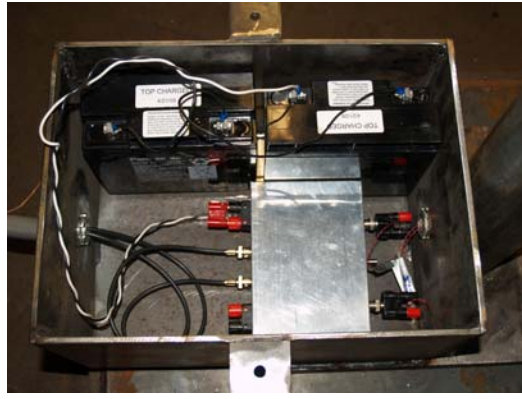Figure 4: Wheatstone Bridge Circuit

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Figure 5: The Wheatstone Bridge Circuit Housing Unit

When the blast bar is impacted, an elastic wave propagates along the bar and induces strain in the gages attached to the bar causing resistance change in the initially balanced circuit, producing an output voltage. The output voltage is directly proportional to the strain as indicated by Equation (1)

$$E = \frac{\varepsilon V_0 k (1 + v)}{2}$$
(1)

where E is output signal (volts); ε is strain; V_0 is the bridge output (volts); k is the gage factor, which is equal to 2.15; v is Poisson's ratio, which has the value of 0.3 for steel.

The strain ε can be calculated using the particle velocity and the compression wave velocity in steel as indicated in Equation 2.

$$\varepsilon = \frac{u}{C_m}$$
(2)

where u is the particle velocity (m/s), which is equal to ½ of striker velocity for a steel on steel impact.; C_m is measured compression wave velocity (m/s), which has the value of 4800m/s.

The impact pressure P (GPa) is then calculated

$$P = \frac{\rho C_m u}{10^6}$$
(3)

where ρ is steel density (g/cm^3)

Calibration of ARL Blast Bar Gauge

Calibration of the bar gauges is necessary so that the recorded output voltage of the Wheatstone bridge can be correlated with the impact pressure. In order to obtain a calibration curve, a series of symmetric impact tests were completed using a modified Hopkinson bar setup with compressed gas gun to launch a half-inch diameter by 19-inch long Vascomax steel striker bar. The velocity of a striker bar was measured while it was inside its launch tube. The velocity was obtained by the

interruption of a light beam at three stations along the launch tube using a photo diode light source and a photo transistor to produce a voltage signal. The velocity between each station was then calculated using the known distance between stations and the measured arrival times. These velocities were used to calculate the acceleration between stations. The velocity was corrected for acceleration to give the true velocity at impact using Equation 4

$$V_s = \left(V^2 + 2ax\right)^{1/2} \tag{4}$$

where V_s (m/s) is the striker bar velocity at the impact; V (m/s) is the striker bar velocity between station #2 and station #3; a (m/s^2) is the acceleration; x (m) is the distance from the midpoint between stations #2 and #3 and the impact face of the bar gauge.

Figure 6 shows the Wheastone bridge calibration curve of pressure versus output voltages for a bridge input voltage of 24 volts. The output voltage E was measured. The impact pressure P was calculated from Equations (2), (3), and (4). One GPa is equal to 10 kbars.

y = 17.942x - 0.6905
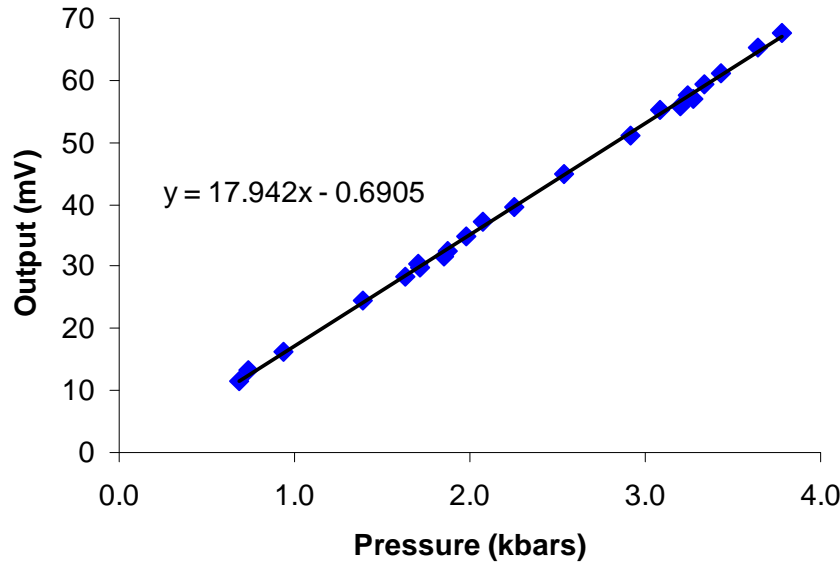
Figure 6: Wheatstone Bridge Calibration

Correction for Dispersion of the ARL Blast Bar Gauge Signal

The propagation of longitudinal stress waves is dispersive because the higher frequency waves have lower phase velocities. The dispersion distorts the stress wave by the time it reaches the strain gauge (about 150 microseconds, corresponding to the 30" distance from the sensing head to the measuring strain gauges). We corrected the signal distortion by applying fast fourier transform (FFT), phase shifting, and inverse fast fourier transform (IFFT) procedures. Figure 7 is a plot of a typical bar gage waveform before any data reduction has taken place. A raw bar gauge output signal spanned three passes of the stress wave due to reflections from the ends of the bar; the signal of interest is the first pass. Figure 8 is a plot of a typical raw strain data and a dispersion-corrected strain data for the explosive charges tested in this study.
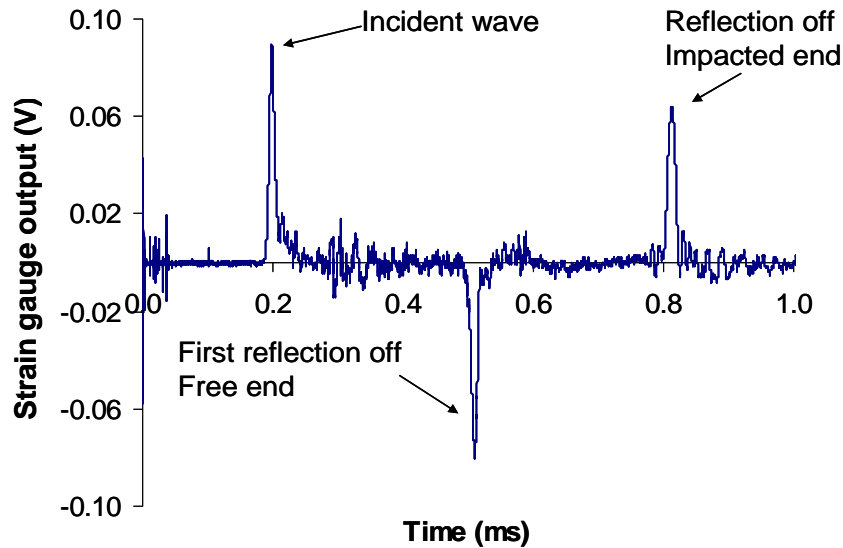
Figure 7: A raw trace from the scope without any correction of an explosive charge detonated 10 inches from the face of the bar. The signal of interest is the first peak at about 0.2 millisecond
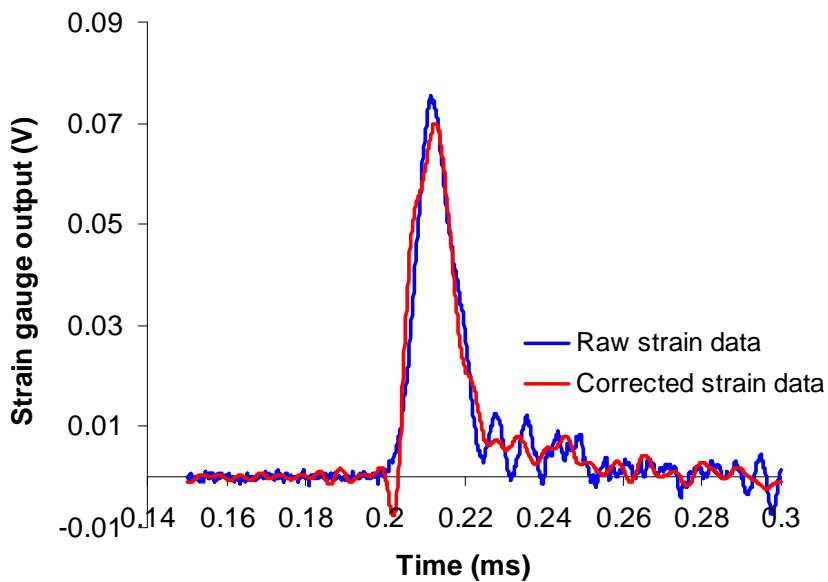

Figure 8: Example of a raw strain data and a corrected strain data of an explosive charge detonated 10 inches from the face of the bar

ARL Blast Integrator (BI) Device

The blast integrator device (BI) is a mechanical device. When the expanding blast wave impacts the BI bar, the supporting steel springs absorb the impulse by compressing. The deflection of the springs was obtained by measuring the displacement of the four polyethylene bushings which move as the spring compresses. By measuring the maximum spring compression and the mass of the bar and its

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supports, and knowing the spring constant, the total impulse delivered to the BI was calculated.

RESULTS

Figure 9 shows the pressure of cylindrical explosive charges on the face of the bar gauge at different standoff distance. The pressure curves were obtained from the Wheatstone bridge output voltage and the blast bar calibration curve. The impulse per unit area could be calculated by integrating the pressure time signal. Figure 10 shows the total impulse of cylindrical charges delivered to the BI at different standoff distances.
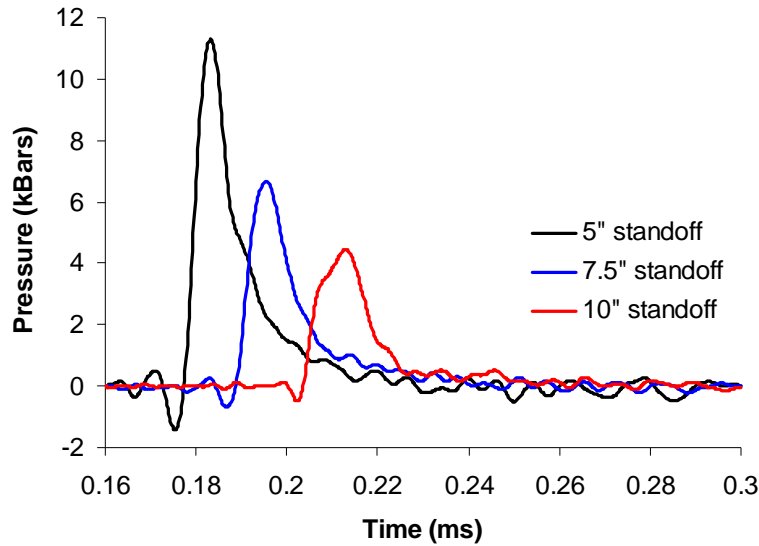
Figure 9: Pressure versus time plots of cylindrical charges measured at 5, 7.5, and 10 inches
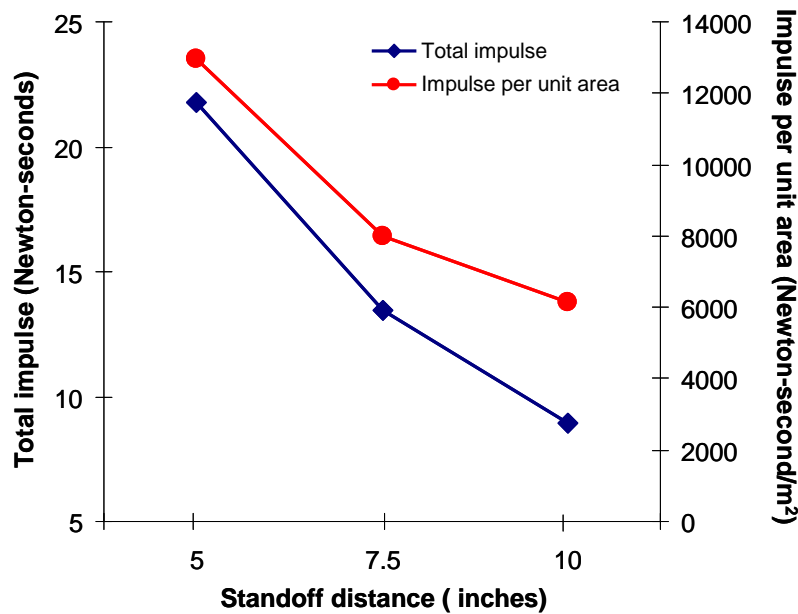
Figure 10: Total impulse and impulse per unit area of cylindrical charges measured on the blast integrator and blast bar gauge

CONCLUSIONS

The blast bar gauge and BI techniques provide a method for evaluating explosive performance from near-field impulse loading. The blast pressure bar gauge and BI have been constructed and obtained reliable near-field blast wave measurements from the lateral surface of a two-inch diameter by four-inch long cylindrical charges (simultaneously initiated at both ends) at standoff distances of 10, 7.5 and 5 inches from the axis of the charge. The blast bar pressure gage gives a pressure-time history of the reflected blast wave at the face of the bar from which the peak pressure and the impulse on the face area of the bar can be derived.

REFERENCES

1. Edwards, E.H., Thomas, G.O., Milne, A., Hooper, G., and Tasker, D. 1992. "Blast wave measurements close to explosive charges", Shock Waves 2: 237-243.

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